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# Modified axial lead system in children[1]

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*Preliminary studies have been made on the use of the modified axial lead system in infancy and childhood. A highly significant correlation between internipple distance and height suggested that internipple distance be used as an index for the selection of a template to facilitate placement of the chest electrodes (Z and X). A series of 4 triangular templates was designed. The use of a template one size too large or too small was shown not to lead to any significant error in waveform measurement. A further study showed that the reference level for the application of the praecordial electrodes should be the 5th intercostal space as for adults, but that no serious diagnostic error was likely to arise if the 4th or 6th intercostal space was chosen by mistake. A study of the Frank lead system suggested that the use of the 5th intercostal space as a reference level was more appropriate than the 4th intercostal space, which is generally adopted by users of that system. The conclusion reached was that the axial lead system is the preferred orthogonal lead system for children, with templates for 4 ranges of internipple distance (<10 cm; 10 to 15 cm; 15 to 20 cm; and >20 cm—adult build) being proposed to simplify electrode placement.*

Three orthogonal lead electrocardiography is being used increasingly among adults but relatively little has been published on this subject in childhood. A few papers have described normal ranges in a limited number of children (Hugenholtz and Liebman, 1962; Namin and D'Cruz, 1964; Namin *et al.*, 1964; Liebman *et al.*, 1966; Ainger, 1967; Khoury and Fowler, 1967; Gamboa and White, 1968; Liebman *et al.*, 1971; Liebman *et al.*, 1973) but more extensive studies are needed. In our laboratories, a project has been established to define normal values for 3 orthogonal lead electrocardiographic measurements derived from the modified axial lead system (Macfarlane, 1969) applied to a large population of infants and children.

At the outset the need for a simple method to facilitate the positioning of chest electrodes in infancy and childhood was required. The originators of the axial lead system (McFee and Parungao, 1961) suggested that where the subject was a child, the standard distance (6 cm) adopted in the adult to separate the 3 anterior chest electrodes (Z–) from the central reference point of the equilateral triangle formed by them (Fig. 1) should be reduced in proportion to the height of the subject. Similarly the separation of the lateral X+ electrodes is height dependent.

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Were this rule to be strictly applied to each subject the work involved would be complicated and would constitute a serious obstacle to the adoption of the system on a wide scale. An even greater difficulty could be expected to arise from the acknowledged difficulty of ensuring accurate measurements of height (or length) in the first two or three years of life when stable electrocardiographic recording requires the least possible disturbance to the subject. We decided, therefore, to seek a method for electrode application whereby a small number of triangular templates might be constructed, their size and application being determined by some simple measurement which accurately reflected linear growth in infancy and childhood. As part of the study, it was decided to check whether the use, in error, of a triangular template of a larger or smaller size than that required would substantially affect the recording.

McFee and Parungao (1961) indicated that the reference point with respect to which the praecordial electrodes should be centred in the adult was 2 cm from the left sternal edge in the 5th intercostal space; they considered this to be the centre of gravity of the heart. During much of infancy and childhood the heart is at a higher level in the thorax than in the adult, with the apex beat in the 4th left intercostal space so that its centre of gravity should also be above the 5th interspace. We decided to determine whether variation in the choice of reference level was clinically important in these age groups. The longitudinal reference was chosen to be 1 cm from the left sternal edge in infants and children.

Guller *et al.* (1974) have shown that displacement of the E electrode of the Frank (1956) system in infants causes considerable alteration in the vectorcardiographic loops derived from the 3 orthogonal lead electrocardiogram. This system has also been criticised for its particular sensitivity to any change in the interspace chosen for the application of the chest electrodes. Langner *et al.* (1958) proposed that the 4th intercostal space be used as the reference level for supine patients rather than the fifth, which Frank (1956) had suggested for subjects in an erect posture. It was decided, therefore, to make a limited study with the Frank system on the effect of interspace variation in infants and children.

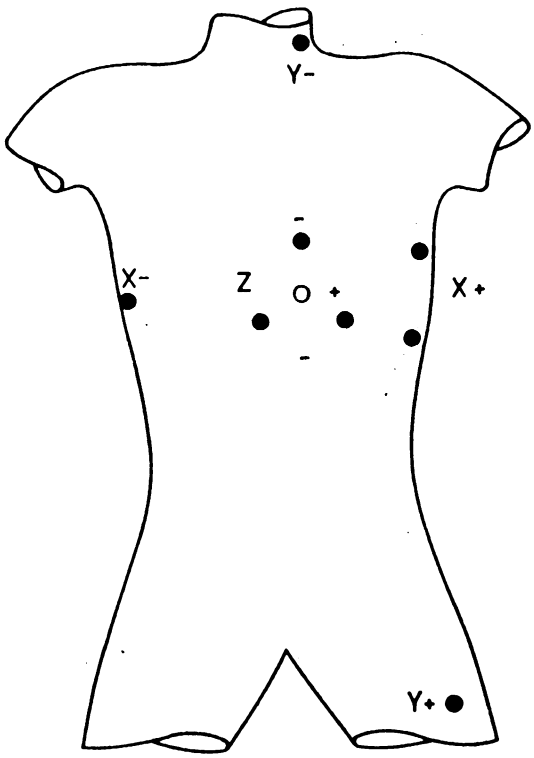


Fig. 1 *The electrode placements of the axial lead system. The reference point for the positioning of electrodes in adults was proposed as the 5th intercostal space, 2 cm to the left of the sternal margin. The X+ electrodes are placed symmetrically about the horizontal plane through this point with a separation of 11 cm in the adult, one-third of distance from the front to the back of the thorax. The X− electrode is placed at the reference level in a corresponding longitude on the right side of the chest. The Y+ electrode is usually placed on the left leg and the Y− electrode is positioned on the left side of the neck. The three anterior (Z−) electrodes are positioned at the apices of an equilateral triangle, each being 6 cm from the reference point (in the adult). This distance is also height dependent. The Z+ electrode is positioned on the back, at the reference level and directly behind the reference point.*

## Subjects and methods

### (a) SELECTION OF TEMPLATE SIZE

A total of 139 children between the ages of birth and 14 years (Table 1) was studied to determine whether or not there was any correlation between age, height, and certain other physical measurements which might serve as a guide to the selection of template size.

Measurements were made of trunk length (distance from vertebra prominens to tip of the sacrum), total body length, and the distance between the centre of each nipple. Infants were measured supine; older subjects were measured standing.

Subsequent to the choice of a series of triangular templates to facilitate the placement of the Z-electrodes, 24 subjects between the ages of 4 and 13 years were studied to determine the effect of using a template of incorrect size. In each case, the Z-electrodes were applied in accordance with the dimensions of (i) the correct triangle, (ii) the next larger triangle, and (iii) the next smaller triangle. The measurements derived from each recording for the purpose of comparisons were the maximum QRS vector magnitude ( | QRS | ), the angle in the transverse plane made by the projection of the maximum QRS vector ($QRS_T$), the amplitude of the R wave in the anterolateral lead X ($R_X$), the amplitude of the S wave in lead Z ($S_Z$), and the amplitude of the T wave in the anteroseptal lead ($T_Z$). For each of five parameters, comparisons were made between the measurements derived from recordings with the correct template size and those from the other two electrocardiograms, using the paired t test. It should be noted that, in practice,

Table 1 *Age distribution of 139 infants and children studied for correlation of age, height, etc.*

| *Age groups* | *No. of subjects* |
|---|---|
| 0– 6 d | 24 |
| 1–51 w | 31 |
| 1– 3 y | 20 |
| 4– 6 y | 37 |
| 7–10 y | 13 |
| 11–13 y | 14 |
| | 139 |

the polarity of lead Z was inverted so that an $S_Z$ wave reflects movement of current towards the back.

(b) CHOICE OF INTERSPACE (AXIAL LEAD SYSTEM)

To explore the effect of changing the reference level for the chest electrodes, axial lead electrocardiograms were recorded with the 4th, 5th, and 6th intercostal spaces each as reference levels in 79 children and on the 4th and 5th interspaces in 29 infants, 18 of whom were neonates. In order to test the effect of variation of interspace with size of the child, these subjects were placed in four groups on the basis of internipple distance (Table 2).

The 295 electrocardiograms from these 108 children were analysed by a computer programme described previously (Macfarlane and Lawrie, 1974). The measurements selected for statistical purposes were | QRS | , $QRS_T$, $R_X$, $S_Z$, and $T_Z$ as before. Comparisons of the measurements in records centred on adjacent interspaces were made using the paired t test.

(c) CHOICE OF INTERSPACE (FRANK SYSTEM)

A separate group of 61 children aged between 4 and 14 years was studied using the Frank lead system. The 3 orthogonal lead was recorded in the supine position twice, with the reference level taken on the first occasion as the 4th intercostal and on the second, as the 5th intercostal space. The 122 electrocardiograms obtained were analysed by the same programme as used for the axial lead data. This is allowable, since only QRS and T wave amplitudes were being considered with the diagnostic section of the programme being ignored. The wave recognition procedures used were thus the same for both the Frank and the axial lead systems.

## Results

(a) SELECTION OF TRIANGULAR TEMPLATE SIZE FOR Z− ELECTRODES

Correlation coefficients relating height (length), age, and internipple distance are shown in Table 3, where the 139 children have been subdivided by age only (Table 1). Additional correlations were carried out for the 69 boys and 70 girls as two separate groups and these results are shown in Table 4. The correlations within each of the age groups were not as good as the overall correlation, as might have been expected. Trunk length correlated equally well with height ($r=0.95$ for girls and $r=0.97$ for boys) as did internipple distance.

On the basis of these results, internipple distance —being more easily measured than trunk length— was chosen as representative of height in prepubertal children. Four sizes of triangular template for the Z+ electrodes were designed to be used in conjunction with a table of internipple distance ranges (Table 5) representing the period from birth

Table 2 *Distribution of 108 children with respect to internipple distance to determine effect of varying reference level for electrode positioning*

| *Group* | *Internipple distance (cm)* | *No. of subjects* |
|---|---|---|
| A | < 8 | 18 |
| B | 8–8·9 | 11 |
| C | 9–12·9 | 24 |
| D | > 13 | 55 |
| | | 108 |

Table 3 *Correlations between height, age, and internipple distance classified by age*

| *Age groups* | *No. of subjects* | *Internipple distance v height* | *Age v height* | *Age v internipple distance* |
|---|---|---|---|---|
| 0– 6 d | 24 | 0·566 | 0·199 | 0·337 |
| 1–51 w | 31 | 0·857 | 0·842 | 0·846 |
| 1– 3 y | 20 | 0·463 | 0·744 | 0·327 |
| 4– 6 y | 37 | 0·671 | 0·551 | 0·015 |
| 7–10 y | 13 | 0·636 | 0·806 | 0·676 |
| 11–13 y | 14 | 0·617 | 0·209 | 0·159 |
| | 139 | | | |

Table 4 *Correlations between measurements of height, age, and internipple distance, obtained from 69 boys and 70 girls*

| *Female* \ *Male* | *Internipple distance* | *Age* | *Height* |
|---|---|---|---|
| Internipple distance | | 0·87 | 0·95 |
| Age | 0·92 | | 0·88 |
| Height | 0·96 | 0·96 | |

Table 5 *Template sizes for preliminary study, subdivided by internipple distance*

| *Group* | *Internipple distance (cm)* | *Δ (cm)* | *X+ (cm)* |
|---|---|---|---|
| A | ⩽7·9 | 2 | 3·5 |
| B | 8–8·9 | 3 | 5·5 |
| C | 9–12·9 | 4 | 7 |
| D | ⩾13 | 5 | 9 |

Δ, distance from centroid to apices of triangle formed by 3 Z− electrodes. X+, separation of X+ electrodes.

to puberty. The four groups were formed empirically from inspection of the scattergram of height v internipple distance (Fig. 2).

When measurements from electrodes applied in accordance with the correct triangle were compared with those arising from the use of a triangular template one size larger or smaller, no significant difference was discovered in 9 of the 10 measurements. However, slightly lower values for $S_Z$ were obtained when a larger triangle than required was used. The probable explanation is that the triangle of larger size had the effect of positioning all three Z- electrodes further from the electrical centre of the heart, thus causing a decrease in the amplitude of the major deflection in the Z lead, i.e. the S wave.

### (b) CHOICE OF INTERSPACE (AXIAL LEAD SYSTEM)

Correlation between measurements made at adjacent interspaces using the axial lead system on the four different subgroups of children separated with respect to internipple distance are summarised in Tables 6 and 7. Because numbers in the two groups with the smallest subjects were less than in the other groups, they were combined; this did not lead to any material difference in the results and the combined figures are not, therefore, presented. No significant difference between any of the values measured at the 4th and 5th intercostal spaces could be determined in the two groups containing the smallest subjects. In general, in these two groups, there was little difference between the mean amplitude and the different interspaces. With the one angular measurement ($QRS_T$) there was a large difference in the mean values but this was not statistically significant, because of the very large standard deviation.

In the remaining two groups of children correlations were made between measurements in the 4th and 5th, and in the 5th and 6th interspaces. In the group with internipple distances in the range 9 to

Table 6 *Correlations between electrocardiographic measurements recorded using modified axial lead system with reference level at 4th and 5th interspace*

| | A | B | C | D |
|---|---|---|---|---|
| $R_X$ | 0·79 | 0·92 | 0·86* | 0·85 |
| $S_Z$ | 0·83 | 0·94 | 0·95 | 0·95 |
| $T_Z$ | 0·31 | 0·72 | 0·57 | 0·87 |
| \| QRS \| | 0·90 | 0·96 | 0·90 | 0·92 |
| $QRS_T$ | 0·32 | 0·75 | 0·99 | 0·99 |

Groups A, B, C, and D refer to internipple distance as indicated in Table 2.
*A statistically significant difference between measurements at different interspaces, even though correlation is high ($P < 0·05$).

Table 7 *Correlations between electrocardiographic measurements recorded using modified axial lead system with reference level at 5th and 6th interspaces*

| | C | D |
|---|---|---|
| $R_X$ | 0·75 | 0·80 |
| $S_Z$ | 0·94* | 0·94 |
| $T_Z$ | 0·91 | 0·85 |
| \| QRS \| | 0·85 | 0·89 |
| $QRS_T$ | 0·99 | 0·98 |

Groups C and D refer to internipple distance indicated in Table 2.
*Statistically significant difference between measurements at different interspaces, even though correlation is high ($P < 0·05$).

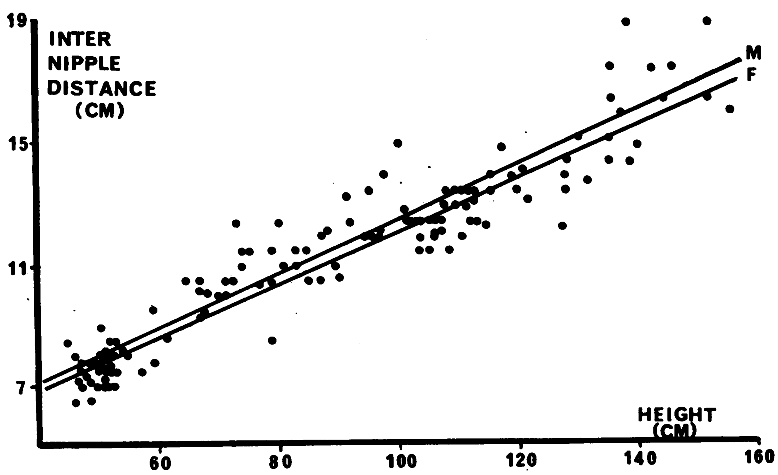


Fig. 2 *The scattergram of height and internipple distance formed from measurements on 70 girls and 69 boys aged from birth to 13 years. The regression lines for boys (M) and girls (F) are also shown. The equations are (a) for girls: internipple distance = 0·088 height + 3·3; (b) for boys: internipple distance = 0·092 height + 3·4.*

12·9 cm the R wave amplitude in the anterolateral lead (lead X) was significantly greater in the 5th than in the 4th interspace. No other comparison showed any significant difference between measurements at these two interspaces. Comparison of measurements between the 5th and 6th interspaces showed the only significant difference to be the amplitude of the S wave in the anteroseptal lead (lead Z) which was greater when recorded at the 5th interspace. With the fourth group of children with internipple distances of 13 cm or more there was no significant differences between any of the measurements compared.

(c) CHOICE OF INTERSPACE (FRANK SYSTEM)
The 61 patients who had a Frank system orthogonal electrocardiogram were taken as a single group for the purpose of statistical analysis; this was valid since the paired t test was being used with each subject as his own control. In only one instance, viz. the maximum QRS spatial vector magnitude, was there any significant difference between measurements made using the 4th and 5th interspaces, the higher voltage being recorded from the 5th interspace.

## Discussion

McFee and Parungao (1961) recommended that in childhood the spacing of the three anterior chest electrodes of the axial system should be adjusted in proportion to the height of the subject. It was considered to be impractical in routine electrocardiography to measure the height, especially of small children, before making a recording. Accurate measurement would be difficult to achieve without disturbing the child, thereby creating a situation which would be far from ideal for the recording of an adequate electrocardiogram. It was, therefore, necessary to find a simpler measurement which would reflect height and could act as a guide to the choice of a template for positioning the electrodes. Our data showed that, while there was good correlation between age and height beyond 1 year as might be expected, there was an even better correlation of height with internipple distance in both boys and girls in this largely prepubertal population. The simple measurement of internipple distance was, therefore, adopted as an index of height with respect to which the triangular electrode placings would be chosen.

The subdivision of subjects by internipple distance into four groups is somewhat arbitrary and the appearances in the scattergram (Fig. 2) could justify various groupings. The error in positioning the three anterior electrodes using a template rather than in strict proportion to the patient's height is minimal and of no consequence. It was found that the use of a triangle larger or smaller than required also produced little change in the electrocardiogram. It has already been shown by Duchosal (1966) that rotation of the three chest electrodes through 60° produces no appreciable difference in the anteroseptal lead wave form. Therefore any error of the order of a few millimetres in positioning the electrodes will be of no consequence.

Likewise the spacing of the two left lateral chest electrodes is determined by the choice of template; the upper and lower electrodes can be most conveniently sited on either side of the reference level by using the length of one side of the template as a measure of X+ electrode separation. Any inaccuracy in positioning arising from this method would be minimal and almost certainly less than the actual diameter of electrodes normally used for recording the orthogonal lead electrocardiogram.

For these reasons, at the completion of the study, it was decided to choose a subdivision of internipple distance that could be easily remembered by technicians. Measurements of 10 cm, 15 cm, and 20 cm were selected as dividing lines for selection of template size and templates of appropriate size were constructed (Fig. 3). Table 8 shows template sizes and their relation to average height and internipple distance.

In spite of the fact that in the child, by contrast with the adult, the 4th intercostal space must, on clinical grounds, be closer to the physical centre of gravity of the heart than is the 5th intercostal space, the electrocardiogram did not suggest that the electrical equivalent dipole was at the higher interspace. With the axial system no significant difference emerged between measurements centred on the 4th and 5th intercostal space reference levels, with the exception of $R_X$ which favoured the 5th interspace in one of the four groups. No appreciable diagnostic error would be likely to arise

Table 8 *Recommended template sizes for use with modified axial lead system*

| *Internipple distance (cm)* | Δ | *X+* | *Average height* |
|---|---|---|---|
| < 10 | 2 | 3·5 | 55 |
| 10→15 | 3 | 5·5 | 85 |
| 15→20 | 4·5 | 8 | 130 |
| > 20 | 6 | 11 | 170 |

Δ, distance from centroid of Z− triangle of electrodes to each electrode.
X+, corresponding separation of 2 X+ electrodes. Approximate average heights of subjects in each group are noted.

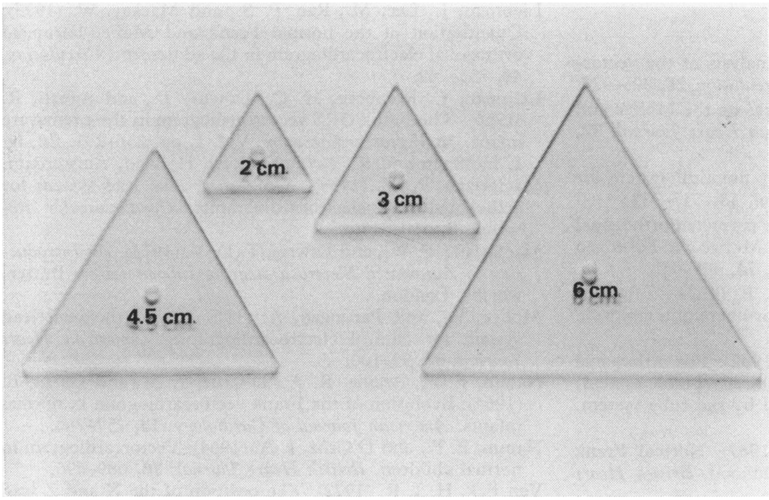


Fig. 3 *Perspex templates of four different sizes. The distances 2 cm, 3 cm, 4·5 cm, and 6 cm denote the distance from the centroid to the apices of each triangle and are recommended for children with internipple distances up to 10 cm, 15 cm, 20 cm, and over 20 cm, respectively. The latter applies to juveniles of adult build.*

if the 4th interspace were mistakenly selected instead of the 5th intercostal space. While there was no significant difference in angular measurements at different interspaces, the most dramatic change was observed in this value. This applied both to the axial system and the Frank system in the smallest subjects. No specific pattern to explain these differences was found. It is likely, however, that open vector loops in the transverse plane are responsible in that a shift of interspace may alter the pattern sufficiently to change the position of the maximum vector as illustrated in Fig. 4. The 5th intercostal space used in adults as the reference level for the thoracic electrodes in the axial system seems equally appropriate to some older children in the upper centile ranges for height and weight and approaching adult build. Moreover, with no evidence having been adduced from our studies to favour the selection for any age group of the 4th

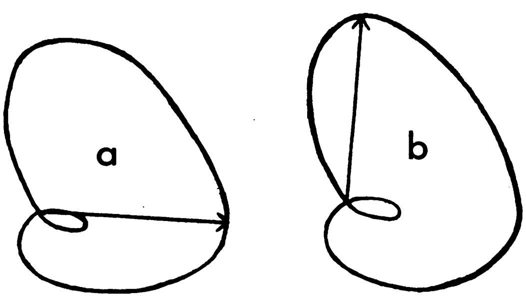


Fig. 4 *An illustration of how two similar vector loops, (a) and (b), may have maximum planar vectors separated by approximately 90°.*

intercostal space, it is logical to propose that the 5th interspace should be used as the reference level for all children.

Proponents of the axial system claim one of its advantages to be substantial freedom from error as a result of electrode misplacement. Some rotation of the praecordial electrode triangle has already been found not to lead to any significant change. We have now shown that a shift of the reference level from the 5th to the 4th or from the 5th to the 6th interspace does not cause changes of diagnostic significance. These findings strongly support the view that it is the axial nature of the lead field of this system rather than a meticulous placement of all the electrodes which ensures the orthogonality of the lead vectors and a stable electrocardiogram.

Guller *et al.* (1974), in their study of the Frank system in 50 children, have shown considerable changes in vector loops with displacement of only one of the anterior chest electrodes. Van Eck (1972) criticised the Frank system on theoretical grounds suggesting that the choice of the 4th interspace for use in children was questionable. In our study of the Frank system, the QRS vector magnitude was significantly higher in voltage ($P < 0{\cdot}05$) in the 5th intercostal space as compared with the 4th. These data suggest that the 5th interspace is the reference level of choice for the Frank system as it is for the axial lead system. This finding must cast some doubt on normal ranges previously published for the Frank system in children and confirm the suspicions of others as to the variability of this system in children. These studies support our view that the axial system is the orthogonal lead system of choice in children.

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